

INFLUENCE OF PLASTIC FINES ON COMPACTION AND SHEAR STRENGTH CHARACTERISTICS OF SOIL MIXTURES

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ABSTRACT: In case of non-availability of local earth for the construction of highway embankments, pavements, retaining structures, the selection criteria for borrowing the earth is made to the quality of fines irrespective of quantity of fines. It is necessary to understand the effect of quantity of fines on mechanical behavior of soil mixtures. With this objective, the plastic fines completely exclusive of coarse are added to the coarse fraction/sand completely free from fines in the proportion of 5% to 50% by weight of the sand. The compaction characteristics, moist and saturated Shear strength (i.e Shear strength at OMC & SMC) values of mixture in different proportion are determined. The results clearly indicated the fact that, there is a specific Critical Fines Content (CFC) for the mixture, such that the presence of plastic fines up to this critical fines content (CFC) is beneficial in terms of improving the gradation and increase in shear strength values. The CFC for the soil used in the study was found to be 30%. Hence, this study is useful to the practicing Civil Engineers in predicting the behaviour of soil mixtures based on the plastic fines content. Further, this study suggests the need for inclusion of quantity of plastic fines in addition to their quality in relevant Codes of practice.

Keywords: plastic-fines, compaction, shear-strength, SPSS, regressions

1. INTRODUCTION

The occurrence and distribution of soils in nature is such that, the various types of soil can be found together. Most of the studies concerning the stress-strain and shear strength behavior of granular soils mainly inspected the response of clean sands. However, field observations show that granular soils may contain a considerable amount of clay and/or silt. Therefore, these fines should be expected to influence the engineering behaviour of sandy soils. Several instances are reported wherein soil mass with highly plastic fines but in very low proportion are rejected even though its saturation Shear strength values are satisfactory. It is therefore necessary to investigate the role of plastic fines possessing objectionable PI value on the design parameter Shear strength when the fines are in different percentages. Efforts are made in this direction in the present study.

1.1 Literature Review

Until recently, few studies have reported on the behavior of granular sandy and/or clayey soil with different fines contents. Georgiannou V.N. (1988), made an investigation on the behavior of clayey sands under monotonic and cyclic loading [1]. Mehmet, M. M. and Gurkan O.,(2007), investigated on the compression behavior of clayey sand [2]. Sreedhar, M.V.S., et al. (2009), investigated on the role of fines content on CBR value of sand-clay mixtures and proposed a Critical Fines Content (CFC). They reported that, fines in excess of CFC transform the load bearing mechanism from cohesion-less behaviour to cohesive behaviour governed by plasticity [3]. Shaker, A., Elkady, T., and Dhowian, A. (2014), investigated the swelling and compressibility characteristics of a sand-natural expansive clay mixture for use as a hydraulic barrier [4]. Vu To-AnhPhan, et al. (2016), investigated on the effects of fines content on cohesion, internal friction angle and critical state in the consolidated undrained shear test of sand-fines mixtures. [5]

2. OBJECTIVES

The primary objective of this work is,

- To study the influence of plastic fines on the Shear strength characteristics of the soil mixtures.
- To understand the role of plasticity of fines on Shear strength characteristics of the soil mixture in soaked conditions.
- Identification of the “Critical Fines Content” for the soils used in this study, above which the plastic fines start influencing the geotechnical behavior of soil mixtures.
- To explore the possible correlations between the percentage of fines and the Shear strength values.

2.1 Scope

The scope of present study is limited to, investigation of influence of fines on soil mixtures involving one type of sand and plastic fines only. Further, the scope is limited to observe the mechanism at macroscopic level i.e in terms of Shear Strength.

3. METHODOLOGY

The methodology includes

- Collection and characterisation of materials
- Formulation of Scheme of Experiments
- Conducting compaction and Direct Shear tests as per scheme of experiments
- Analysis of results and formulation of conclusions.

3.1 COLLECTION AND CHARACTERIZATION OF MATERIALS

The materials used in this study are natural sand as coarse fraction and black cotton soil as plastic fines.

3.1.1 Natural Sand

Locally available river sand is used for the present study. The summary of the index and engineering parameters of the tests done in accordance with the respective Indian Standard specifications are shown in the Tables 1 and 2 given below. Based on the tests done, the soil is classified as well graded sand (SW).

TABLE 1: SUMMARY OF INDEX PROPERTIES OF NATURAL SAND

S.No.	Properties	Values
1	Results of Wet Sieve analysis	
	Gravel size %	4.60
	Coarse Sand size %	10.90
	Medium Sand size %	49.80
	Fine Sand size %	33.50
	Fines %	1.20
	Coefficient of uniformity of sample Cu	6.92
	Coefficient of Curvature Cc	1.05
2	Specific Gravity (G)	2.67

3	Classification of sand	SW
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TABLE 2: SUMMARY OF ENGINEERING PROPERTIES OF NATURAL SAND

S.No.	Properties	Values
1	IS Heavy Compaction Test	
	Optimum Moisture Content (OMC) %	13.20
	Maximum Dry Density(MDD) (kN/m ³)	19.30
2	CBR value under a surcharge of 5 kg.	
	i. Un-soaked (%)	23.00
	ii. Soaked (4 days) (%)	15.40
3	Shear parameters from Direct Shear Test	
	At OMC	
	Cohesion 'c' (kN/m ²)	0
	Angle of Shearing resistance 'Φ'(degrees)	42.00
	At SMC	
	Cohesion 'c' (kN/m ²)	0
	Angle of Shearing resistance 'Φ'(degrees)	38.65

3.1.2 Plastic Fines

Black Clay collected from Siddipet area of Karimnagar district crossing Mid Manair R/S Canal at chainage 0.900 km along embankment alignment on Rajiv Rahadari, has been used as plastic fines for the present investigation. The summary of the results of both index and engineering properties are shown in the Tables 3 and 4 below. Based on these results, the soil is classified as 'CH'.

TABLE 3: SUMMARY OF CHARACTERISTICS OF PLASTIC FINES

S.No.	Properties	Values
1	Wet Sieve analysis	
	Gravel size %	0.20
	Coarse Sand size %	0.60
	Medium Sand size %	5.70
	Fine Sand size %	12.20
	Silt size %	18.50
	Clay size %	62.80
2	Specific Gravity (G)	2.60

3	Atterberg's Limits	
	Liquid Limit (LL) %	52.50
	Plastic Limit (PL) %	21.20
	Shrinkage Limit (SL) %	15.20
	Plasticity Index (PI) %	31.30
4	DFSI %	46.00
5	Classification of soil	CH

TABLE 4: SUMMARY OF ENGINEERING PROPERTIES OF PLASTIC FINES

S.No.	Properties	Values
1	IS Heavy Compaction Test	
	Optimum Moisture Content (OMC) %	15.20
	Maximum Dry Density(MDD) (kN/m ³)	18.40
2	CBR value under a surcharge of 5 kg.	
	Un-soaked (%)	15.40
	Soaked (4 days) (%)	4.80
3	Shear parameters from Direct Shear Test	
	At OMC	
	Cohesion 'c' (kN/m ²)	63.0
	Angle of Shearing resistance 'Φ'(degrees)	8.31
	At SMC	
	Cohesion 'c' (kN/m ²)	27.0
	Angle of Shearing resistance 'Φ'(degrees)	3.90

3.2 PROPORTIONING OF MATERIALS

The soil mixtures were obtained by uniform blending of plastic fines and sand in different proportions as shown in Figure 1. The natural sand is washed thoroughly out of fines of size minus 75 microns and oven dried. Clean oven dried sand has been mixed with different proportions of black clayey soil (plastic fines) to form different sand-clay soil mixtures. Fines contents of the soil mixtures used as 5, 10, 20, 30 and 50 percent by weight of sand. While proportioning, care was taken to account for the coarser fraction present in clayey soil such that the overall coarse and fines content of the mixture makes up to the designated proportion.

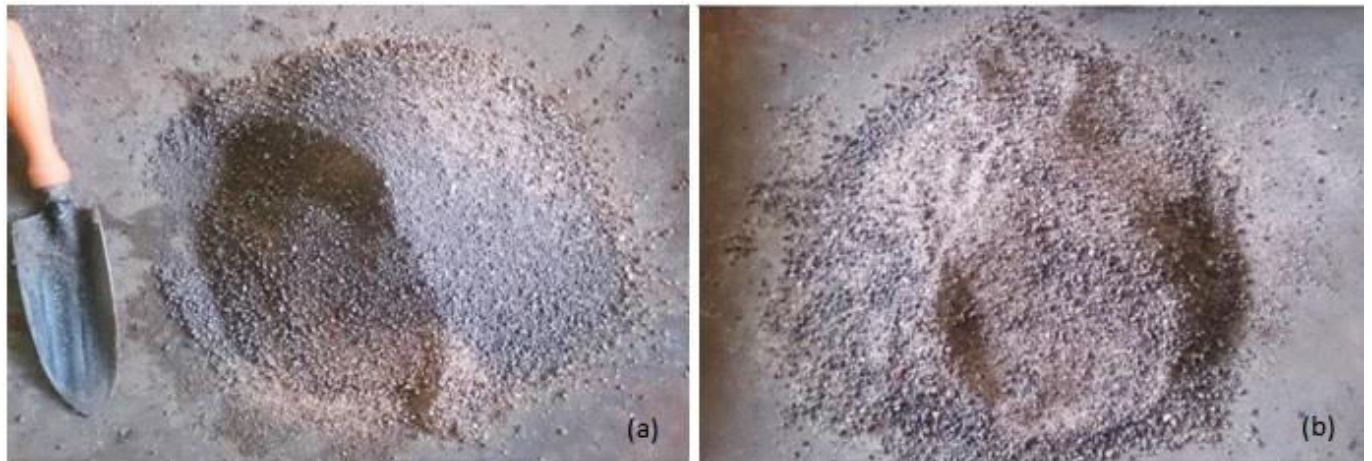


Fig.1 : (a) addition of fines in sand (b) blending of sand and fines

3.3 COMPACTION AND DIRECT SHEAR TESTS

The IS Heavy compaction tests were done on mixtures of different fines content as per IS:2720 (Part-7)-1980. The Direct Shear test has been performed in accordance with Indian standard code of practice IS: 2720-XIII as shown in Figure 2.



Fig.2 Direct Shear Testing

4. RESULTS AND DISCUSSIONS

The results of different tests performed in this study are presented in this section. The variation of different test parameters is analysed and relevant observations are made.

4.1 GRAIN SIZE DISTRIBUTION

The variation in particle size distribution with increase in fines content is shown in Figure 3.

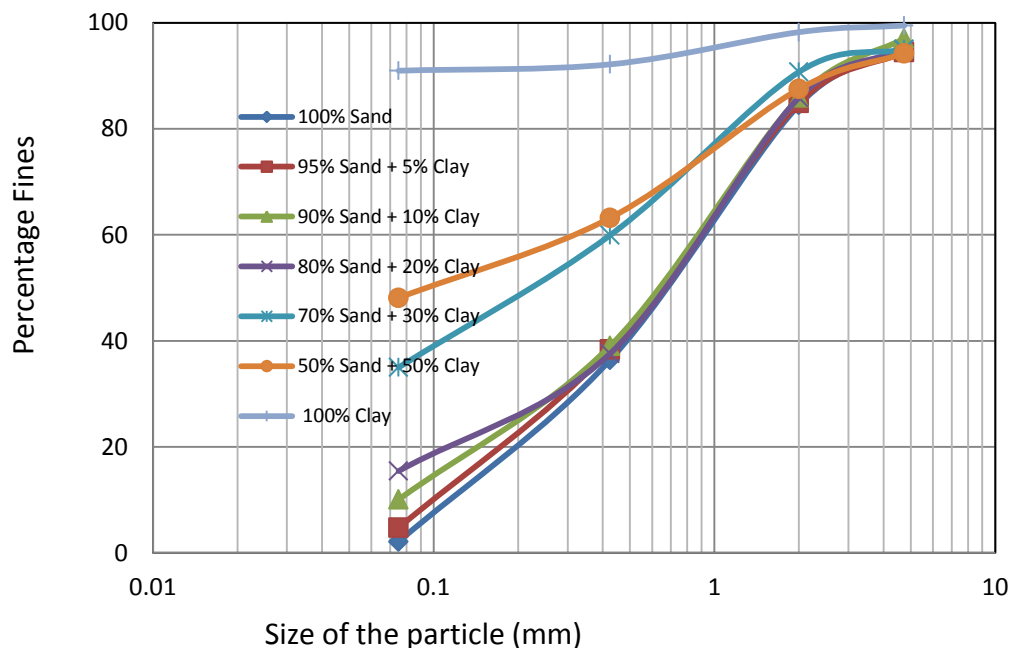


Fig. 3 Variation in Particle size distribution with increase in fines content

4.2 PLASTICITY INDEX

The variation in plasticity index with increase in fines content is presented in Figure 4. The plasticity index is increasing proportionately with the increase in fines content. It is important to note here that, the plasticity index is essentially a characteristic feature of plastic fines dependent on its mineralogy. Theoretically, if same plastic fines are used in different mixtures, the plasticity index should have been the same. However, as the specimen for determination of consistency limits is recommended as - 0.425mm, it is possible that, the fine sand size particles may also become part of the specimen. Hence, the plasticity index is governed by relative proportion of non-plastic and plastic fines within the test specimen.

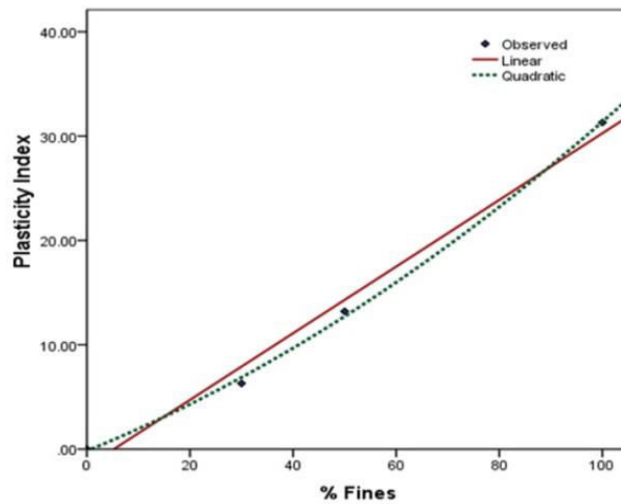


Fig.4: Variation in Plasticity Index with percentage fines

The correlation between the plasticity index and fines content is presented in Equation 1 below.

$$PI = -1.675 + 0.319F \quad (R^2 = 0.986) \quad \dots \text{Eq.1}$$

Where:

PI = Plasticity Index

F = Percentage of fines content

4.3 COMPACTION CHARACTERISTICS

The results of IS Heavy compaction tests performed on different soil mixtures are summarized in Table 5.

TABLE 5: SUMMARY OF COMPACTION TEST RESULTS

S.No.	Sand (%)	Fines (%)	OMC (%)	MDD (kN/m ³)
1	100	0	13.80	19.29
2	95	5	12.00	19.33
3	90	10	11.00	19.90
4	80	20	11.20	21.00
5	70	30	11.80	21.50
6	50	50	13.60	20.80
7	0	100	15.20	18.40

4.3.1 Optimum Moisture Content

The variation in OMC with increase in fines content is presented in Figure 5. It may be seen that, the OMC is decreased up to 20% fines content and increased thereon. The higher OMC at no plastic fines stage may be attributed to the typical sand behaviour wherein capillarity shifts the OMC. The drop from 0% to 20% fines may be attributed to the gradual drop in capillarity on one hand and improvement in gradation on the other hand. The increase in OMC beyond 20% is due to increased specific surface with increase in fines content.

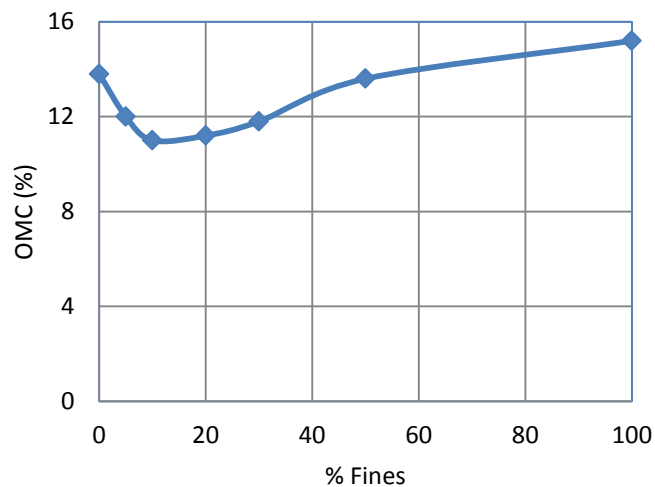


Fig. 5: Variation in OMC with fines content

The percentage change in OMC with increase in fines content is presented in Figure 6.

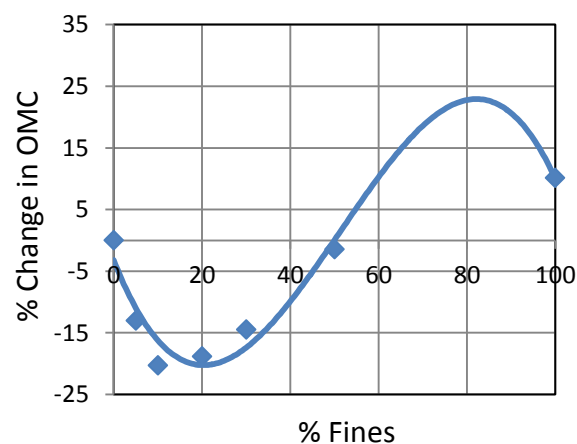


Fig. 6 : Variation in Percentage change in OMC with fines content

The regression equation describing the percentage change in OMC is given below.

$$\Delta OMC = -0.0004F^3 + 0.0562 F^2 - 1.8302 F - 3.1888 \quad (R^2 = 0.944) \quad \dots \text{Eq.2}$$

Where

ΔOMC = Percentage change in optimum moisture content over that for zero plastic fines;

F = Percent plastic fines content.

However, the nature of polynomial infers that, its validity is more appropriate in plastic fines content from 0 to 50% than beyond.

4.3.2 Maximum Dry Density

The variation in MDD with percentage plastic fines is presented in Figure 7.

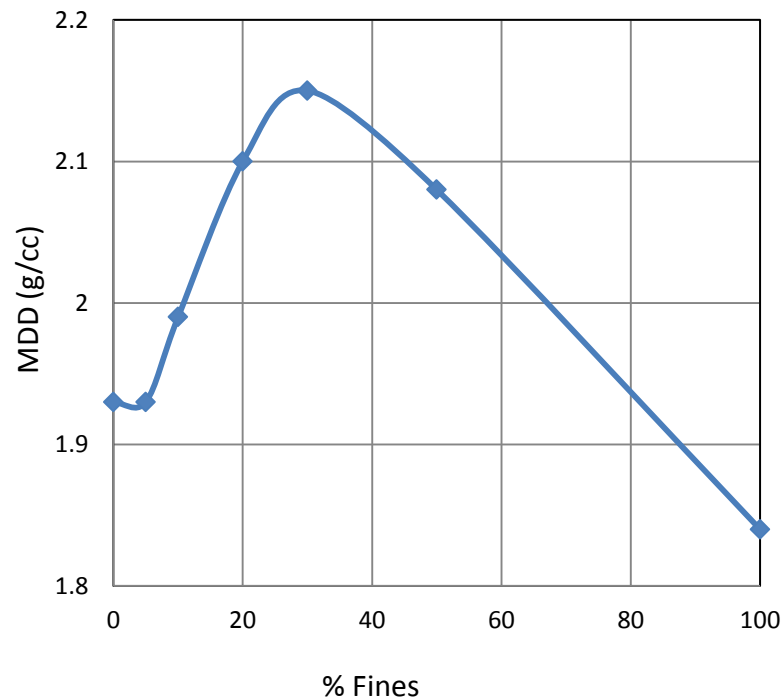


Fig. 7 Variation in MDD with plastic fines content

Based on Figure 7, the following observations can be made.

1. The MDD was least influenced till fines content was up to 5%. This may be for the reason that, these fines are likely to reside in the relatively larger voids with still unfilled empty space.
2. However, the MDD is increasing beyond 5%, showing a peak point at 30% and then decreasing steadily. The increase in MDD is due to the void spaces between the sand particles are occupied by the finer particles. Upto 30% substitution, the fines contributed to improvise the gradation of soil and hence resulted in increased MDD.
3. However, fines in excess of 30% may have contributed to change the gradation to poorly graded and hence causing a reduction in MDD. Further, with higher fines content, the relative ease with which particles can move under compaction effort gets decreased due to cohesion, resulting in a lesser MDD.

The percentage change in MDD with fines content is presented in Figure 8. A maximum percentage increase of 11.77% was observed at 30% fines due to improvement in gradation of the mixture.

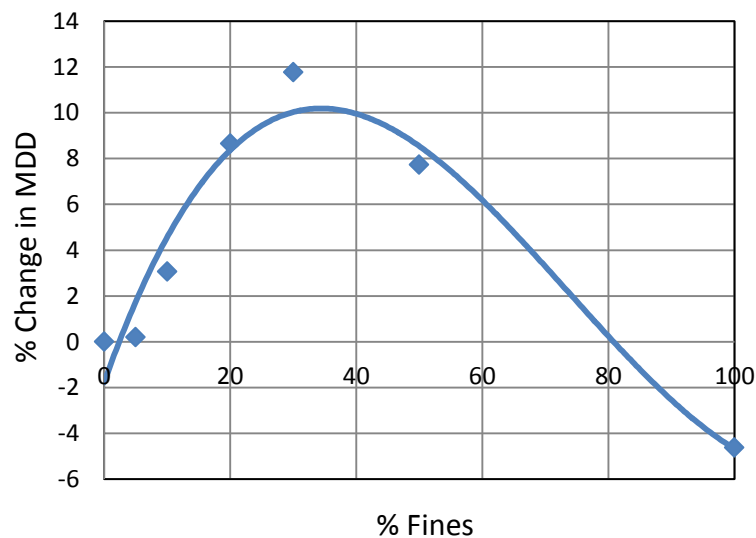


Fig. 8: Variation in Percentage change in MDD with plastic fines content

The regression equation for percentage change in MDD is as given below.

$$\Delta M = 0.00007F^3 - 0.0147F^2 + 0.7736F - 1.7693 \quad (R^2=0.942) \quad \dots \text{Eq.3}$$

Where;

ΔM = Percentage change in MDD over that for zero plastic fines.

4.4 SHEAR STRENGTH

The Direct shear tests were performed on the specimen of different soil mixtures prepared at moist and saturation state. A normal stress ' σ ' of 100 kN/sqm is assumed for estimating the shear strength values.

TABLE 8: SUMMARY OF SHEAR TEST RESULTS

S.No.	Sand (%)	Clay (%)	Shear Strength (kN/sqm) for assumed $\sigma = 100$ kN/sqm	
			@OMC	@SMC
1	100	0	90.0	80.00
2	95	5	88.50	79.30
3	90	10	88.60	79.10
4	80	20	91.60	76.90
5	70	30	96.60	76.30
6	50	50	95.10	73.10
7	0	100	80.00	46.80

4.4.1 Shear strength at OMC

The variation in Shear strength values at OMC with increase in plastic fines content is presented in Figure 9 below.

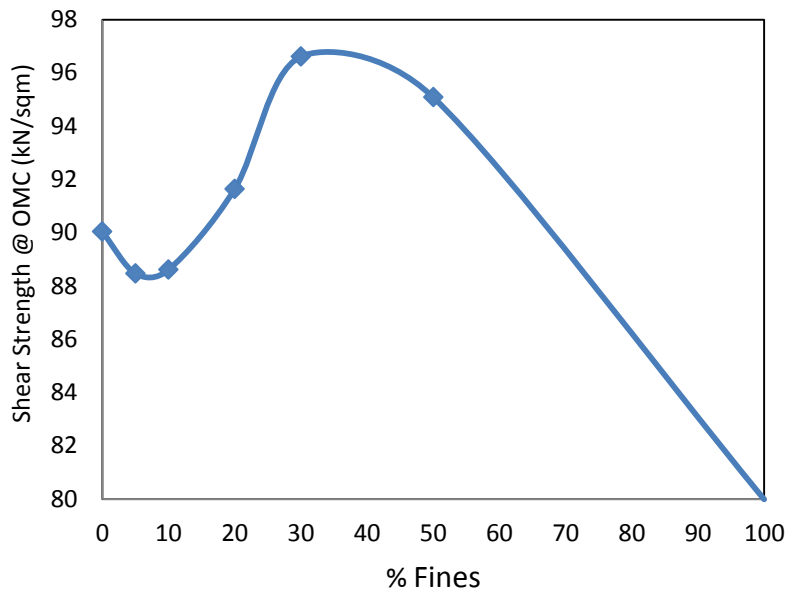


Fig. 9: Variation of Shear strength at OMC value with fines content

Based on Figure 9, the following observations are made.

1. Keeping the normal stress constant, the shear strength values at optimum condition are showing the same trend as that of MDD with the increase in fines percent which says that, the higher the MDD value, the higher is the shear strength of the soil mixture which is at a percentage of 30% fines fraction.
2. At greater percentages, plastic fines are likely to form membrane around the sand particles contributing to reduced angle of shearing resistance and increase in cohesion.
3. When the plastic fines is greater than 50%, the sand and silt grains are essentially floating in a clay matrix and have little effect on the engineering behavior. A maximum increase in percentage of about 7.30% in shear strength value is seen at a fines content of 30% which can be seen in Figure 10.

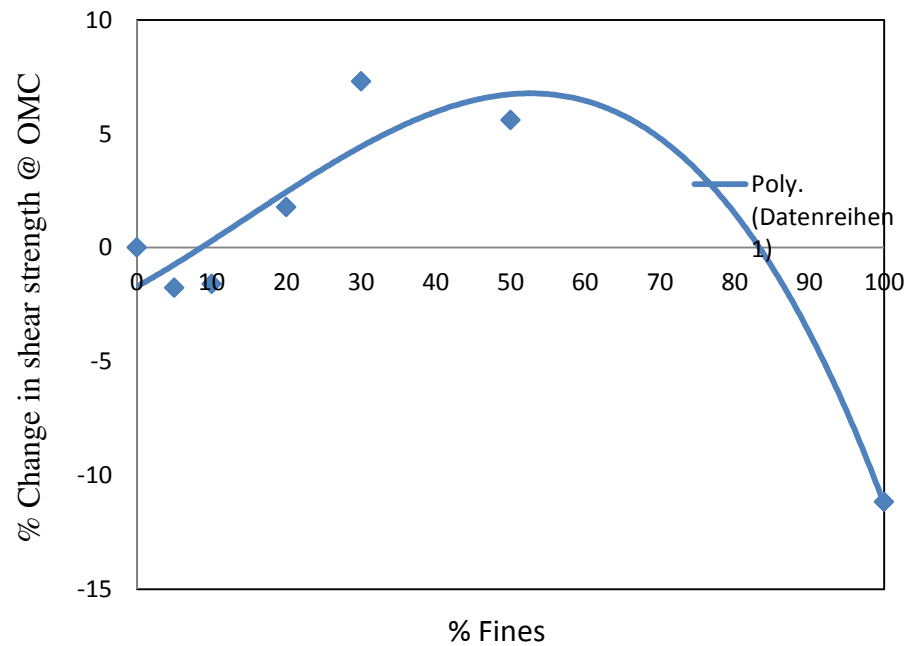


Fig. 10: Variation of percentage change in Shear strength at OMC value with fines content

The regression equation describing the change in shear strength value is given in Eq. 4 below.

$$\Delta\tau_o = -0.04981F^3 + 0.0022F^2 + 0.1842F - 1.7153 \quad (R^2 = 0.919) \quad \dots \text{Eq.4}$$

Where $\Delta\tau_o$ = Percentage change in shear strength at OMC

4.4.2 Shear strength at SMC

The variation in Shear strength at saturation condition values with increase in plastic fines content is presented in Figure 11 below.

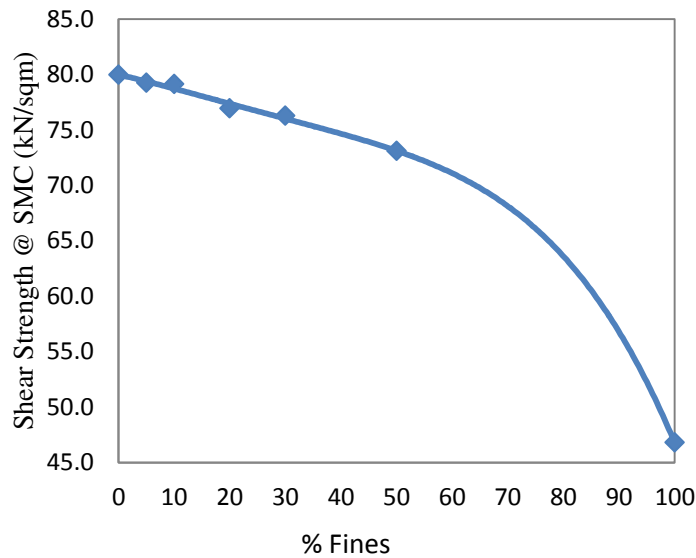


Fig. 11 Variation of Shear strength at SMC value with fines content

Based on Figure 11, the following observations are made.

1. A marginal decrease in the shear strength values at saturation state can be seen upto 10% fines content. After which a gradual decrease can be seen from 10% - 30% of fines substitution.
2. A steep drop in the value at 100% of fines is seen which is due to the highest plasticity of the soil due to saturation.

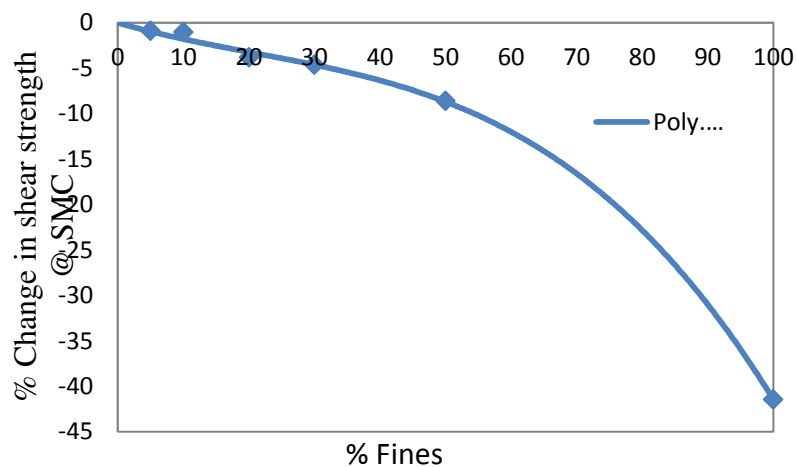


Fig. 12: Variation of percentage change in Shear strength at SMC value with fines content

A maximum decrease in shear strength value of 41.50% can be seen at 100% clayey soil at saturation which is shown in Figure 12. The regression equation describing the change in shear strength value at SMC is given in Eq. 5 below.

$$\Delta\tau_s = -0.00005F^3 + 0.0034F^2 - 0.2073F \quad (R^2 = 0.999) \quad \dots \text{Eq.5}$$

Where $\Delta\tau_s$ = Percentage change in shear strength at SMC

5. REGRESSION MODELS

In Civil Engineering practice, in certain circumstances, there may not be adequate time or resources to get the engineering properties determined through laboratory or field tests. In such circumstances, prediction of such properties based on the easy to determine properties through correlations will be helpful. In view of this, efforts have been made in this study to constitute regression models using SPSS Software version 24.0 as presented below.

LINEAR REGRESSION ANALYSIS

Model 1: Correlation between Group Index (GI) and Maximum Dry Density (MDD)

For qualitative evaluation of the desirability of a soil as a highway subgrade material, a number referred to as the *group index* as determined in Eq. 6 is widely considered. Higher the value of the group index for a given soil, weaker will be the soil's performance as a subgrade.

$$GI = (F-35)[0.2+0.005(L-40)] + 0.01(F-15)(PI-10) \quad \dots \text{Eq.6}$$

Where GI = Group Index

F = Percentage of Fines/ Fines content

L = Liquid Limit

PI = Plasticity Index

The variation of percentage change in MDD with Group Index is shown in Figure 13 below.

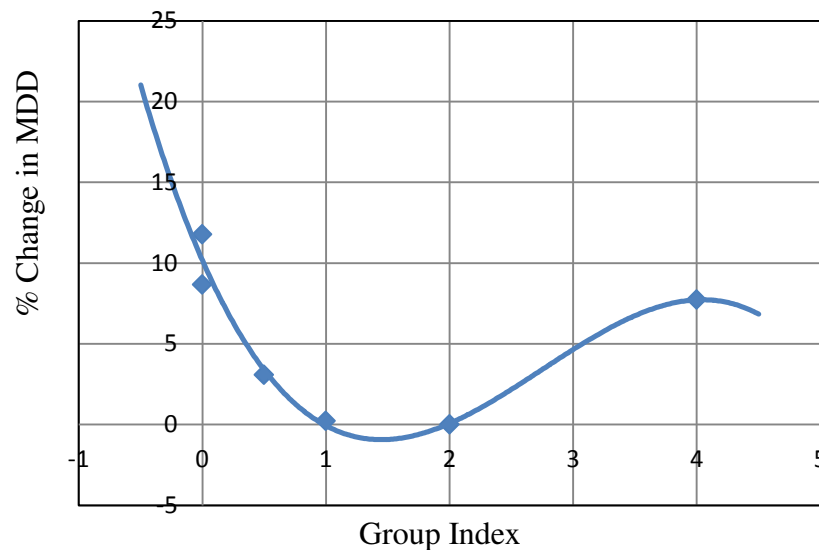


Fig. 13: Variation of Percentage change in MDD with GI

The regression model that describes the correlation between GI and MDD is as given below:

$$\Delta M = -0.9895 * GI^3 + 8.1548 * GI^2 - 17.397 * GI + 10.16 \quad (R^2=0.957) \quad \dots \text{Eq.7}$$

Where ΔM = Percentage change in MDD over that for zero fines; GI = Group Index.

The details of the statistical out-put indicates that the relationship developed between MDD and GI is significant ($\alpha < 0.01$) i.e. at 1% level of significance and also a strong relationship exists between the correlation variables.

Model 2: Correlation between Shear strength and Maximum Dry Density (MDD)

Efforts have been made to develop a correlation between the Shear strength value and the MDD. The percentage change in Shear strength value at optimum condition with MDD is shown in Figure 14 and the regression equation describing the correlation is given in Eq. 8.

$$\Delta \tau_o = 0.9461 * \Delta M - 3.5923 \quad (R^2=0.825) \quad \dots \text{Eq.8}$$

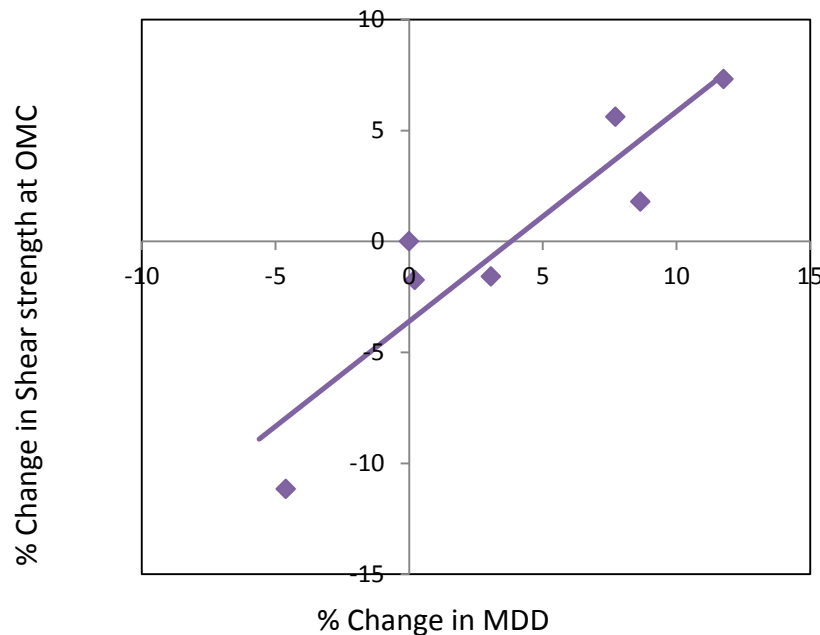


Fig. 14: Variation of percentage change in Shear strength at OMC with percentage change in MDD

The details of the statistical out-put indicates that the relationship developed between Shear strength and MDD is significant ($\alpha < 0.01$) i.e. at 1% level of significance and also a strong relationship exists between the correlation variables.

Model 3: Correlation of Shear strength with PI and MDD

The variation of percentage change in PI, MDD and Shear strength at saturation condition with fines content is shown in Figure 15. The multiple regression equation for correlation of these parameters is presented hereunder:

$$\Delta\tau_s = -0.099 + 0.503 * \Delta M - 1.216 * PI \quad (R^2=0.979) \quad \dots \text{Eq.9}$$

The details of the statistical out-put indicates that the relationship developed between the above parameters is significant ($\alpha < 0.05$) and also a strong relationship exists between the correlation variables.

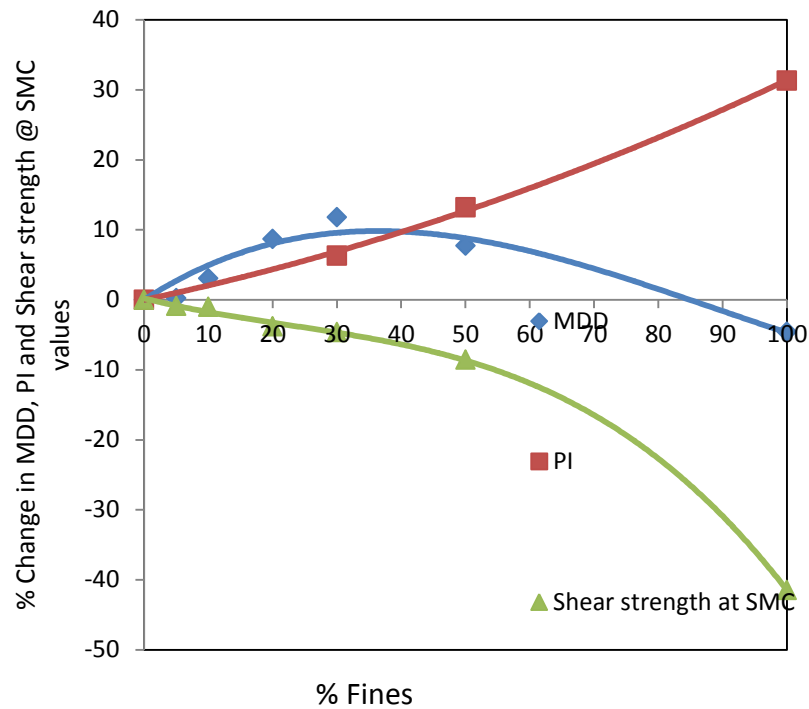


Fig. 15: Variation of Percentage change in Shear strength at SMC, MDD and PI values with fines content

For the developed models, the derived regression coefficients R^2 are neither zero nor less than the standard error. Variance inflation factor (VIF) for the input variables are lower than 10 indicating that there is no multi-collinearity. All the regression coefficients of predictors are also statistically significant. Therefore, the regression coefficients for the predictors of models used to derive the equations for shear strength values can be validated.

6. CONCLUSIONS

Based on the experimental results found in this project, the following conclusions are made.

1. In general, it is found that, apart from the quality, quantity of the plastic fines also has a definite influence on the compaction and Shear strength characteristics of the soil mixtures.
2. As the fines content increases up to a critical value known as "Critical Fines Content (CFC)" the MDD, Shear Strength at MDD & OMC values increases considerably and gradually decreases as fines content increases beyond CFC.

3. For the materials used in this study, the CFC was 30% and the increase in MDD and Shear strength at MDD & OMC was up to 11.77% and 7.30% respectively.
4. The effect of plasticity was more pronounced in saturation state. As the fines content increases the Plasticity Index increases and the Shear Strength at MDD & SMC values continuously decreases owing to the increase in plasticity of the soil mixture. For the materials used in this study, the maximum drop was up to 41.50 %.
5. To facilitate the blending of soils, correlations are developed to predict the effect of fines content on compaction and Shear strength characteristics. The fines content is accounted in easy to determine Group Index (GI). With GI as input, a model (Eq.7) is developed for prediction of percentage change in MDD (viz., ΔM). In turn, the percentage change in Shear strength value can be predicted based on ΔM using (Eq.8). The percentage change in saturated Shear strength value can be predicted as a function of MDD and PI using (Eq.9).

On the whole, this study provided an insight to the effect of fines on compaction and Shear strength characteristics and provides correlations to predict the effect. This study is useful in blending of similar soils.

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